SCARLET I: Mechanization Solutions for Deployable Concentrator Optics Integrated with Rigid Array Technology

516-74
50438
125124

James J. Wachholz* and David M. Murphy*

Abstract

The SCARLET I (Solar Concentrator Array with Refractive Linear Element Technology) solar array wing was designed and built to demonstrate, in flight, the feasibility of integrating deployable concentrator optics within the design envelope of typical rigid array technology. Innovative mechanism designs were used throughout the array, and a full series of qualification tests were successfully performed in anticipation of a flight on the Multiple Experiment Transporter to Earth Orbit and Return (METEOR) spacecraft.

Even though the Conestoga launch vehicle was unable to place the spacecraft in orbit, the program effort was successful in achieving the milestones of analytical and design development, functional validation, and flight qualification, thus leading to a future flight evaluation for the SCARLET technology.

Introduction

The rigid array structural approach chosen for this application was ABLE's flight-qualified PUMA (Pantographically Unfolding Modular Array) design, which is briefly reviewed. The array construction is a hybrid of concentrator (four panels) and planar (two panels) technology so that the non-tracked array functions as both a concentrator flight demonstration experiment and a mission power source at large solar off angles for the nadir-pointing spacecraft. The SCARLET I solar array wing, in the deployed position, is shown in Figure 1.

The main design objective was to integrate the curved Fresnel lens primary optics into the PUMA structure by using simple, controlled deployment mechanisms with accurate optics adjustment features while maintaining the standards of high reliability, small stowed volume, light weight, structural strength, and stiffness. This paper presents the details of the mechanisms designed to accomplish these objectives. The features covered include ABLE's rigid array design, the solar concentrator system, integration of the optics with the deployment system, and the launch restraint system.

* AEC-Able Engineering Company, Inc., Goleta, California

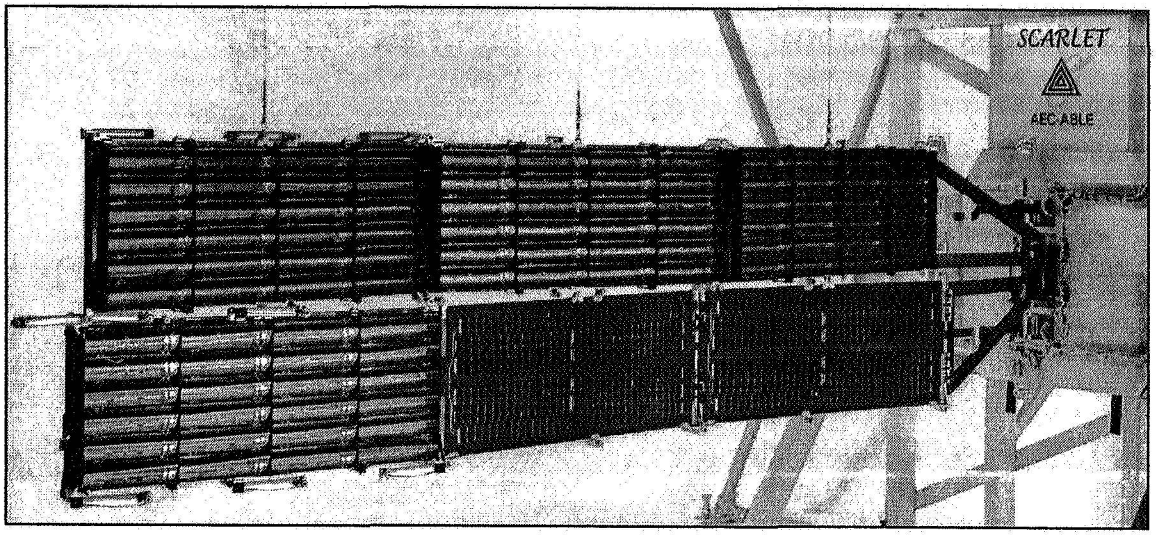

Figure 1. SCARLET I Concentrator Solar Array Wing

Rigid Array Design

Key features of the PUMA rigid array design include pantographic deployment geometry, panels composed of honeycomb substrates with graphite/epoxy face sheets, intrinsic deployment synchronization, redundant deployment springs, small stowed volume, modular design, and high specific power.

Scissors-like array deployment occurs pantographically as the redundantly hinged panels, which are linked in pairs by pivots, unfold until the panels stop 5° short of flat, as shown in Figure 2. By stopping the deployment here, the array retains "depth" to provide substantial gains in structural efficiency with a minimal loss in solar cell power production (Figure 3). Compared to a flat panel array, this technique typically yields a 7.5-times increase in first mode out-of-plane frequency with a small power loss (<0.4%). Structurally efficient panels, composed of aluminum honeycomb with graphite/epoxy face sheets, were used to reduce panel thickness with the added benefit of reducing stowed volume and weight.

Reducing the complexity and increasing the reliability over other rigid panel designs was achieved with the intrinsic self-synchronization of the PUMA pantographic system, which requires no auxiliary timing mechanisms. To complete synchronization down to the root, two stand-off yokes and the panels are hinged together to form a linkage. The timing of the linkage is synchronized with a gear-set at the root.

Multiple redundant torsion springs at each hinge line increase reliability and allow fine tuning of the deployment rate. A viscous damper is also used to control the deployment rate.

This modular rigid array design allows easy addition of panel pairs as needed to meet specific mission requirements during the early design phase.

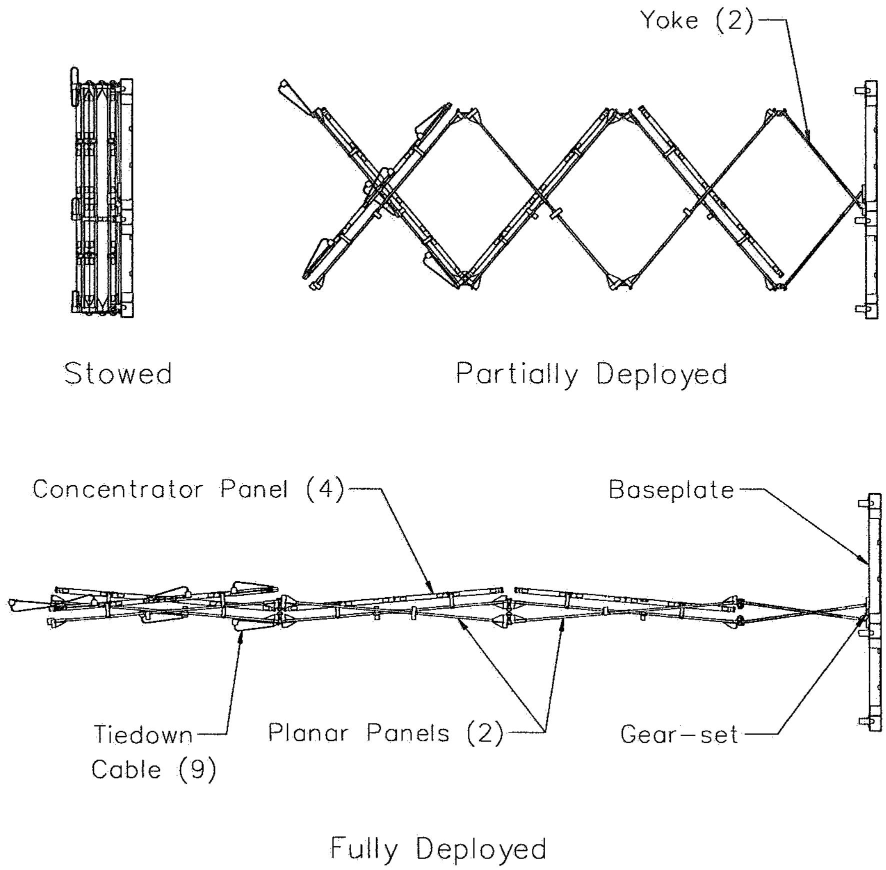

Figure 2. Array Deployment Sequence

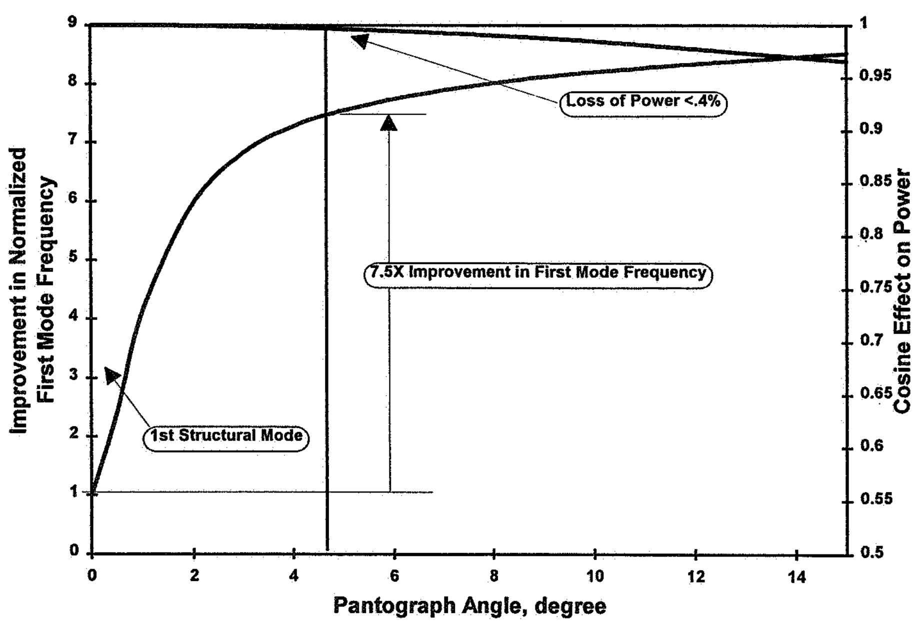

Figure 3. Structural Efficiency Advantage

Solar Concentrator System

The solar concentrating system consists of two optical elements, as shown schematically with ray traces in Figure 4. The primary element is a Fresnel lens composed of 0.006-inch-thick, space-grade silicone bonded to 0.0024-inch-thick, ceria-doped borosilicate glass. The glass, which protects and stiffens the lens, has been thermally shaped as a cylinder to facilitate lamination and to minimize stresses. The refractive Fresnel design yields much better shape error tolerance than reflective concentrating systems.

The compound parabolic concentrator secondary element is made of silicone and is shaped to produce additional concentration by the principle of total internal reflection. The optical system is configured with a tolerance to 2° pointing errors. A detailed description of the optical concentrator system can be found in Reference 1.

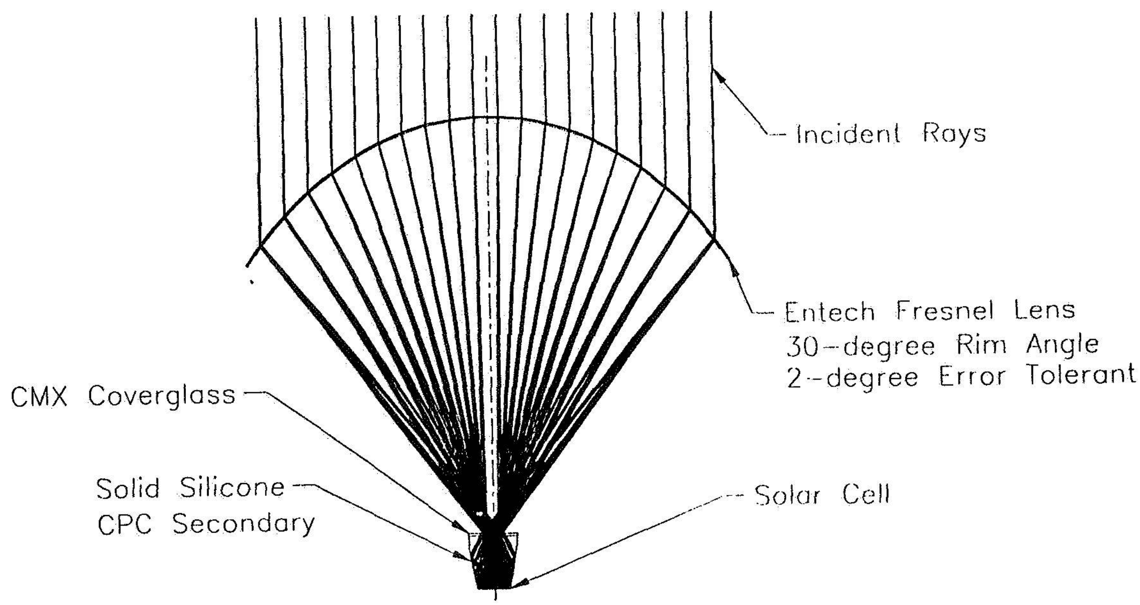

Figure 4. Optical Components

The task of properly supporting and providing for individual adjustability of 24 primary lens assemblies per panel was made challenging by the fact that maintaining a high packing factor is critical to specific power performance. A stiff, lightweight graphite/epoxy frame is used as the primary structure to hold the lenses, as shown in Figure 5. Lenses were bonded with silicone along their long edges into thin-formed steel edge supports. These supports were independently adjustable within the frame, thus allowing the lens to be properly aligned above the secondary optics.

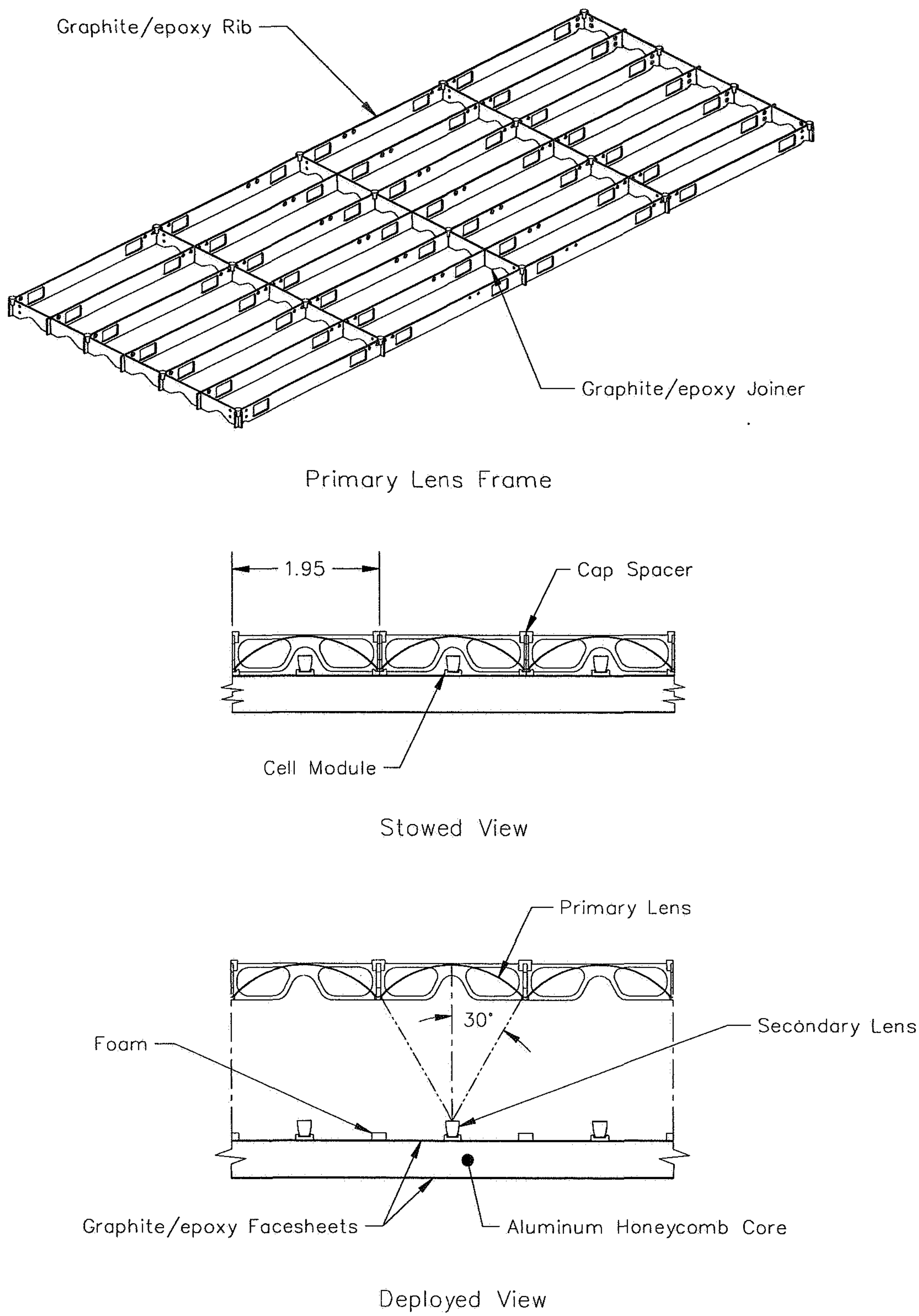

Figure 5. Lens Frame Components

Integration of the Optics with the Deployment System

To maintain low stowed volume, it was determined that the 2.5-inch focal length offset of the primary optics would need to be stowable by collapsing the lens panel down to the structural panel. A trade study was used to determine the optimal method to extend the lens frame assemblies during deployment. Beryllium copper lenticular tapes were chosen because they yield high alignment accuracy, are frictionless, have low stored energy, are lightweight, and have flight history. Figure 6 shows the lenticular tapes deploying the lens frame.

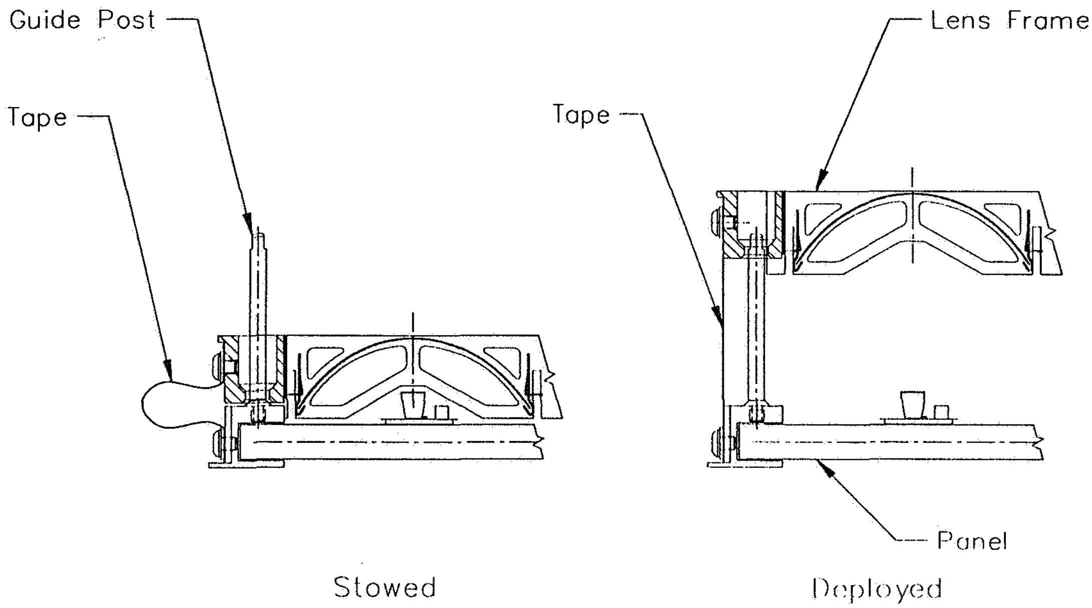

Figure 6. Lens Frame Deployment System

Proper synchronization of the pantographic array panels with their pop-out lens frames was a critical design concern. During preliminary functional testing, interference was noted between neighboring lens frames at a point halfway through the deployment sequence. Mounting small aluminum guide plate pairs to the two interfering lens frames proved to be a simple solution to the interference problem. Figure 7 shows how the guide plates interact with the lens frames during deployment.

Launch Restraint System

Nine cup-cone stackup assemblies are used on the stowed array to transfer launch loads that develop in the panels down to the baseplate via launch cables. The deployable lens panels are sandwiched between their stowed structural panels, which are themselves restrained by the cup-cones. Due to the bilateral geometry of the PUMA, one outboard lens panel and one inboard lens panel are left unrestrained. The inboard lens frame is sandwiched between the structural panel that it is mounted

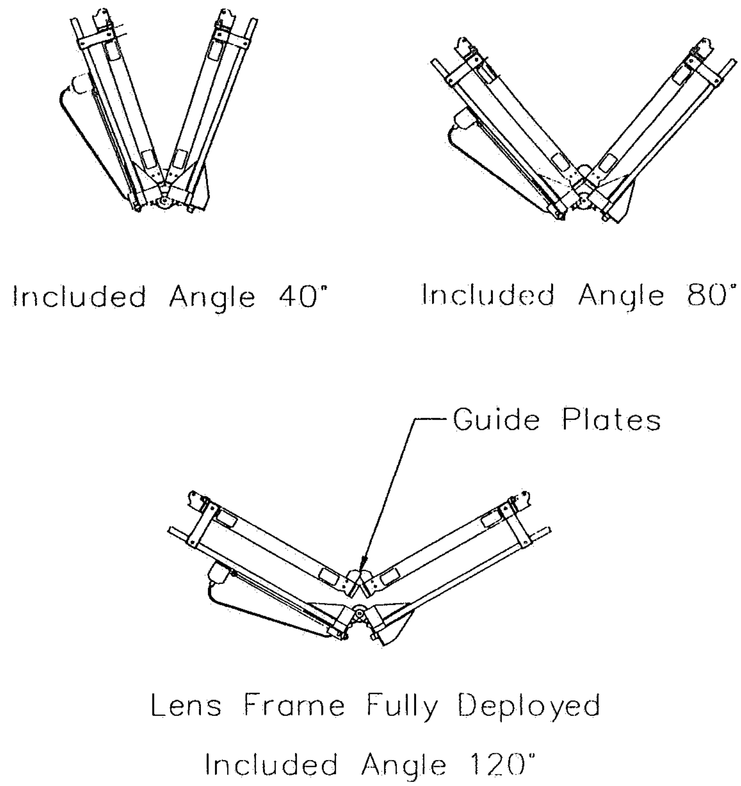

Figure 7. Frame Guide Plate Interaction

to small brackets on the tiedown anchor posts. The outboard lens frame is held in place by cup-cones, contacting the cup-cones of the neighboring panel. Details of the sandwich stack are shown in Figure 8. To compress and preload the stackup, the stainless steel cables of the launch hold-down system are tensioned.

The launch-hold down system consists of three tiedown mechanism assemblies (Figure 9) that each use three cables to secure, in a total of nine places, the panel stack to the baseplate, which is mounted to the spacecraft. The three assemblies are passively staged to release in sequence when given a single command for initiation. In each of the identical assemblies, a highly reliable and resettable high-output paraffin linear motor pushes a notched bar that releases a detent, which then allows a torsion shaft to rotate, thus releasing the three cables from capture fittings. This mechanism has proved to be highly reliable and has been qualified on previous array programs.

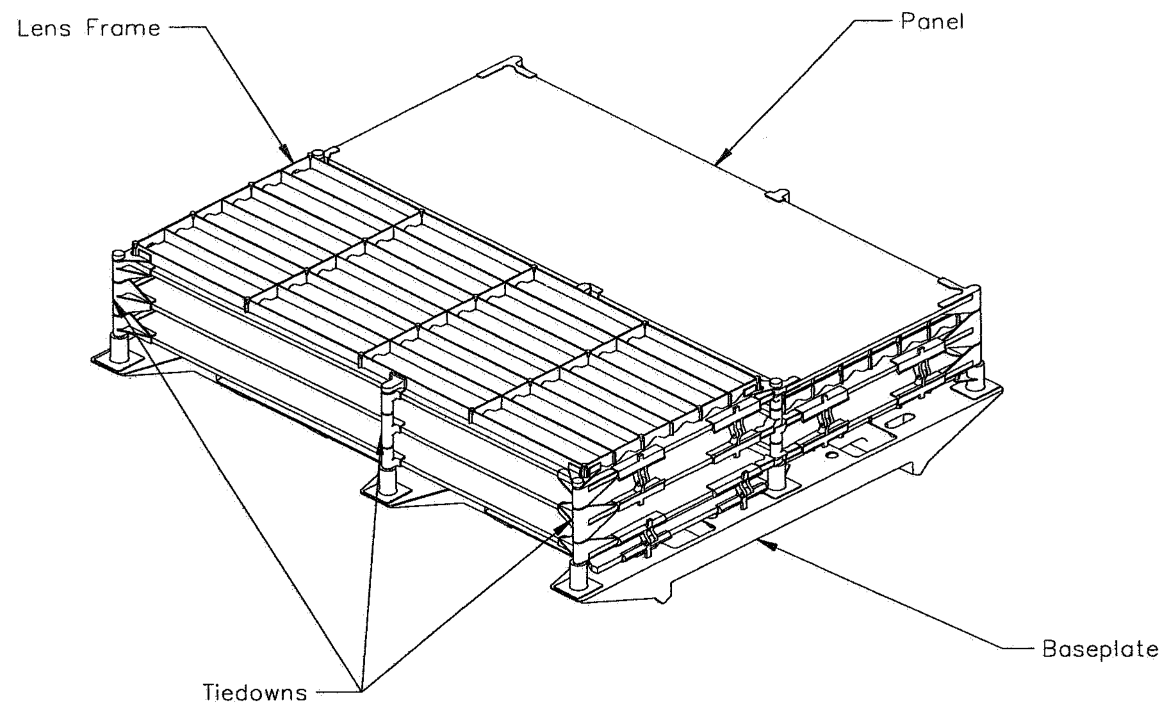

Figure 8. Panel and Lens Frame Stackup to Baseplate

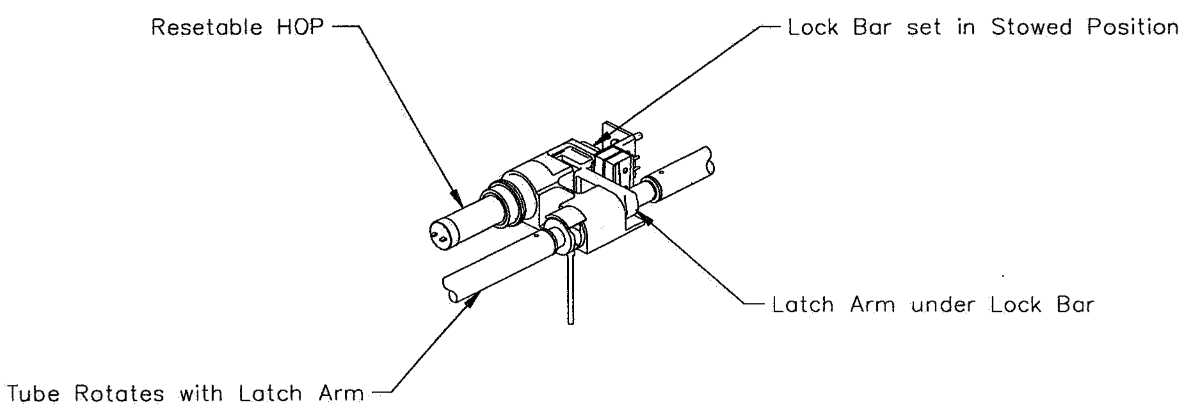

Figure 9. Launch Tiedown Mechanism

To prevent tiedown cables from impacting or shadowing solar cells after deployment, a take-up mechanism is used. This mechanism consists of a lenticular tape folded in half, with one end attached to the top end of the tiedown cable and the other to the panel. As the cable releases from its tiedown mechanism, the lenticular tape pulls the cable out of the panel stackup to a known position that does not interfere with the solar cells. This mechanism provides the added benefit of extracting the tiedown cable completely during panel kinematics, thereby eliminating any possible cable hang-up during deployment. Figure 10 shows the stowed and deployed view of the take-up mechanism.

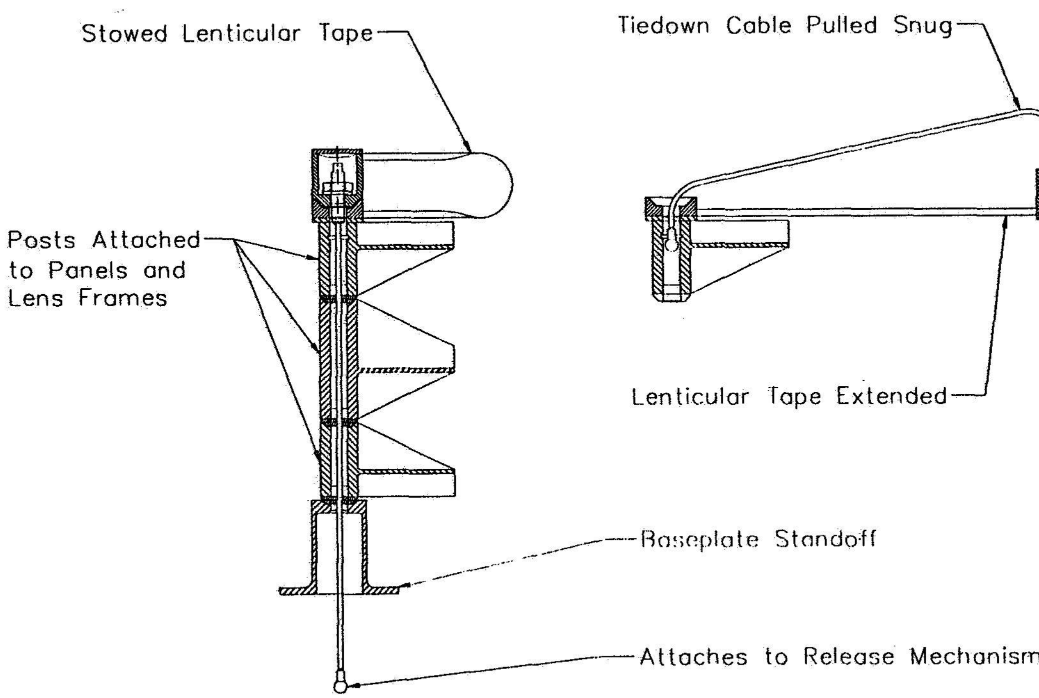

Figure 10. Tiedown Cable Take-up Mechanism

Conclusion

The SCARLET I concentrator array demonstrator program was sponsored by Ballistic Missile and Defense Organization and NASA Lewis Research Center with the ambitious goal of building a flight-ready array in six months (starting from concept) to meet a launch opportunity. SCARLET I was successful in meeting this goal. The array completed a full series of qualification tests and was installed on the NASA METEOR spacecraft.

Many design details were tested successfully for the first time on the flight hardware. Lens adjustment, pop-out panel synchronization, and tiedown integration were successfully mechanized.

Due to the schedule constraints, utilization of a proven and familiar array structure, PUMA, was necessary. In the next phase of the SCARLET program, studies will be undertaken to determine the optimal array structure approach and component design configuration for high specific power at low cost. The SCARLET II array is planned to fly on the New Millennium Deep Space I spacecraft in January, 1998.

References

1. P. Alan Jones, David M. Murphy, and Michael F. Piszczor, "A Linear Refractive Photovoltaic Concentrator Solar Array Flight Experiment", IECEC paper 95-351.

Acknowledgments

ABLE wishes to thank ENTECH, Spectrolab, Composite Optics, and Pilkington for their efforts in successfully delivering atypical hardware assemblies in much less than typical industry time.

ABLE appreciates the funding and support provided by BMDO's Director of Innovative Technologies and the Photovoltaic Sciences branch of NASA Lewis Research Center.